Brief Communications

Human Adipose Tissue Composition and Age

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Although adipose tissue undoubtedly accounts for a relatively large percentage of body weight and although the roles of this tissue as a lipid storage depot and thermal insulator are well recognized (1), remarkably little information is available concerning its gross chemical composition, especially during early life. Such information would seem particularly desirable in view of recent studies suggesting the importance of this tissue as a source of energy in the newborn period (2, 3) and because it may be of major importance in carbohydrate as well as lipid metabolism (4).

Whole-body chemical analyses have provided data on the lipid content of the bodies of infants dying in the perinatal period and of adults (5, 6). The whole-body content of lipid at other ages is unknown although estimates of body composition of a reference infant have been made (7, 8). The lipid content of adipose tissue has been studied by Dju and coworkers (9, 10) in subjects of various ages and by Allen et al. (11) in adults. Because tissues other than adipose tissue contain relatively little lipid (10, 12), an estimate of the size of the adipose tissue compartment can be made at any age if adequate data are available on the lipid content of the body and the lipid content of adipose tissue.

Fatty acid composition of adipose tissue has been reported by several authors (13–16), some of whom found an age-related change.

The present report provides additional data on the composition of adipose tissue at various ages. It also permits a description of the body adipose tissue compartment and its growth during infancy.

METHODS

Samples of both abdominal subcutaneous and perirenal adipose tissue obtained at necropsy from 37 well-nourished individuals (Table 1), were sealed in plastic bags and stored at −15 C. The tissue specimens were subsequently submerged in liquid nitrogen and ground to a fine powder while frozen. Duplicate samples of powdered tissue weighing 1–2 g each were refluxed with 30 ml 95% ethanol in a Goldfish fat extractor for two 6-hr intervals and then with 30 ml petroleum ether (Skellysolve-F) for two additional 6-hr intervals (17). The lipid-containing portions of the four extracts were pooled in a separatory funnel. An equal amount of water was added to the extracts, which were shaken and allowed to stand overnight, after which the water layer was discarded. The lipid fraction was dried by flash evaporation under vacuum to constant weight. The excess solvent was removed from the defatted residue by drying until the weight was constant. The water content of adipose tissue was assumed to represent the difference between fresh weight and combined weight of lipid and residue. The water content was also determined by drying ground nonextracted samples to a constant weight in an oven at 100 C. Results of the two
methods of determining water content were nearly identical (range of ±2%). The nitrogen content of the dried fat-free residue (DFFR) was determined by Dumas combustion, or by acid digestion and microdiffusion (18). The DNA content of the DFFR was determined by a modification of the method of Dische (19), using calf thymus as standard.

The lipid extracts were saponified and the nonsaponifiable fraction was removed in pentane. The FFA were liberated by the addition of hydrochloric acid and extracted into pentane.

*Coleman model 29 Nitrogen Analyzer 1963, Coleman Instruments, Inc.

4 Sigma Chemical Company, 5500 DeKalb Street, St. Louis, Missouri 63118.
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TABLE II

Lipid, water, nitrogen, and DNA of abdominal subcutaneous and perirenal adipose tissue—normal, well-nourished individuals

<table>
<thead>
<tr>
<th>Age</th>
<th>Site</th>
<th>No.</th>
<th>% Lipid Mean</th>
<th>% Lipid Range</th>
<th>% Water Mean</th>
<th>% Water Range</th>
<th>% Nitrogen Mean</th>
<th>% Nitrogen Range</th>
<th>DNA, mg/g fresh tissue Mean</th>
<th>DNA, mg/g fresh tissue Range</th>
<th>Cell number/g fresh tissue Mean</th>
<th>Cell number/g fresh tissue Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Term infants</td>
<td>AS</td>
<td>4</td>
<td>45.3 ± 25.9</td>
<td>39.2-62.4</td>
<td>50.0 ± 15.6</td>
<td>30.7-59.3</td>
<td>0.70 ± 0.2</td>
<td>0.2-0.9</td>
<td>0.67 ± 0.4</td>
<td>0.4-0.8</td>
<td>10.8 ± 10</td>
<td>10.8-20</td>
</tr>
<tr>
<td>stillborn</td>
<td>P</td>
<td>4</td>
<td>35.9 ± 24.3</td>
<td>24-55.5</td>
<td>57.2 ± 14.5</td>
<td>24.3-59.9</td>
<td>0.62 ± 0.8</td>
<td>0.8-1.2</td>
<td>1.20 ± 1.0</td>
<td>0.5-1.5</td>
<td>19.3 ± 10</td>
<td>19.3-30</td>
</tr>
<tr>
<td>Term infants</td>
<td>AS</td>
<td>5</td>
<td>46.8 ± 39.5</td>
<td>5-52.3</td>
<td>45.9 ± 40.5</td>
<td>5-52.8</td>
<td>1.05 ± 0.6</td>
<td>0.8-1.2</td>
<td>2.38 ± 0.9</td>
<td>1.9-1.7</td>
<td>20.6 ± 10</td>
<td>20.6-30</td>
</tr>
<tr>
<td>Birth-48 hr</td>
<td>P</td>
<td>5</td>
<td>45.1 ± 31.7</td>
<td>15-63.2</td>
<td>48.0 ± 31.5</td>
<td>5-59.3</td>
<td>1.04 ± 0.8</td>
<td>0.8-1.2</td>
<td>2.36 ± 1.0</td>
<td>1.9-2.0</td>
<td>27.0 ± 10</td>
<td>27.0-30</td>
</tr>
<tr>
<td>6 Months-10 months</td>
<td>AS</td>
<td>3</td>
<td>68.7 ± 63.4</td>
<td>4.7-74.2</td>
<td>27.2 ± 25.1</td>
<td>1-30.8</td>
<td>0.50 ± 0.4</td>
<td>0.4-0.7</td>
<td>0.63 ± 0.3</td>
<td>0.3-0.9</td>
<td>10.1 ± 10</td>
<td>10.1-20</td>
</tr>
<tr>
<td>21/2 Years-4 years</td>
<td>AS</td>
<td>4</td>
<td>60.4 ± 44.1</td>
<td>17-77.5</td>
<td>31.1 ± 19.1</td>
<td>1-50.2</td>
<td>0.74 ± 0.5</td>
<td>0.5-1.2</td>
<td>0.48 ± 0.4</td>
<td>0.2-0.6</td>
<td>7.9 ± 10</td>
<td>7.9-20</td>
</tr>
<tr>
<td>9 Years-17 years</td>
<td>P</td>
<td>4</td>
<td>48.8 ± 39.2</td>
<td>5-63.8</td>
<td>40.8 ± 37.5</td>
<td>5-54.3</td>
<td>0.65 ± 0.4</td>
<td>0.9-0.9</td>
<td>0.84 ± 0.4</td>
<td>0.6-1.1</td>
<td>13.5 ± 10</td>
<td>13.5-20</td>
</tr>
<tr>
<td>19 Years-25 years</td>
<td>P</td>
<td>7</td>
<td>70.6 ± 66.1</td>
<td>7-78.2</td>
<td>24.2 ± 18.0</td>
<td>20-28.5</td>
<td>0.63 ± 0.3</td>
<td>0.7-1.2</td>
<td>0.39 ± 0.2</td>
<td>0.2-0.5</td>
<td>6.2 ± 10</td>
<td>6.2-20</td>
</tr>
<tr>
<td>38 Years-71 years</td>
<td>P</td>
<td>10</td>
<td>78.9 ± 66.4</td>
<td>8-87.5</td>
<td>18.8 ± 12.3</td>
<td>30.6</td>
<td>0.33 ± 0.1</td>
<td>0.8-1.7</td>
<td>0.18 ± 0.1</td>
<td>0.3-0.3</td>
<td>2.9 ± 10</td>
<td>2.9-20</td>
</tr>
</tbody>
</table>

AS = abdominal subcutaneous. P = perirenal. *Cell number calculated from DNA content (20). They were then methylated with methanolic hydrochloric acid, dried, and taken up in heptane. From each sample an aliquot of 1 ml was then injected into a gas-liquid chromatograph (Beckman GC-4) with 6-ft x ½-inch id stainless steel column with ethylene glycol succinate (EGSS-X) 15% as the liquid phase and Chromosorb-W as the inert support. Each analysis was temperature programmed between 155 and 210 C. A hydrogen flame detector with 40 ml/min helium flow was utilized to determine peaks. The percentage composition of the individual fatty acid methyl esters was calculated from peak areas determined by a potentiometric recorder with disc integrator (Beckman model 1005). Internal standards of known composition were used routinely to identify peak locations. Known mixtures of methyl esters were used periodically to check percentage distribution.

RESULTS

As may be seen from Table II and Fig. 1, lipid accounted for less than 50% of adipose tissue weight in the newborn and for greater percentages as age increased. Concentrations of water, nitrogen, and DNA, on the other hand, decreased with increasing age. The amount of lipid, water, nitrogen, and DNA in the stillborn and less-than-48-hr groups was significantly different from that in older groups by Student's t test. Some tendency was noted for lipid concentration at a specified age to be greater in abdominal subcutaneous than in perirenal adipose tissue (Fig. 1), but this was not statistically significant in any group. The relation between lipid content
and water content of adipose tissue was similar in specimens obtained from the two sites (Fig. 2). In each case, water was inversely proportional to lipid.

The DNA content of perirenal adipose tissue was higher than subcutaneous adipose tissue at each age level. The difference was significant at the 2% level in stillborn infants. At no other age level was the difference between tissue sites significant.

![Fig. 2. Adipose tissue. Lipid-water relationship. Closed circles = abdominal subcutaneous adipose tissue. Open circles = perirenal adipose tissue.](image)

If cell numbers are calculated from DNA content (20), the cell number per gram of wet adipose tissue decreases with increasing age (Table 11). While total nuclei per unit of tissue includes stromal cells to a variable degree (21), the direction and magnitude of the change is worthy of note. (See COMMENT.)

The influence of age on fatty acid composition of adipose tissue was striking (Table 11). In comparison with adipose tissue of adults, that of the newborn infant was significantly higher in palmitic (C16:0) and palmitoleic acid (C16:1) and lower in oleic acid (C18:1). In the stillborn infant group, linoleic acid levels were significantly higher (P < 0.01) in perirenal adipose tissue than in subcutaneous tissue. In no other group was the difference between tissue sites significant.

**COMMENT**

On the basis of data presented here, together with those available in the literature, calculations relating to growth of adipose tissue during early life may be made. Whole-body chemical analyses suggest that lipid comprises approximately 11% of body weight in the neonate (6). The lipid content of adipose tissue at birth

**TABLE III**

Fatty acid composition of adipose tissue from normal, well-nourished individual subjects (mean values)

<table>
<thead>
<tr>
<th>Age</th>
<th>Site</th>
<th>No.</th>
<th>8:0</th>
<th>10:0</th>
<th>12:0</th>
<th>14:0</th>
<th>16:0</th>
<th>15:1</th>
<th>18:0</th>
<th>18:1</th>
<th>18:2</th>
<th>20:0</th>
<th>20:1</th>
<th>20:4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Term infants, still-</td>
<td>AS</td>
<td>4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>2.9</td>
<td>41.9</td>
<td>14.2</td>
<td>3.4</td>
<td>33.9</td>
<td>2.9</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>born</td>
<td>P</td>
<td>4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>4.3</td>
<td>41.9</td>
<td>11.3</td>
<td>4.9</td>
<td>30.5</td>
<td>7.1</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Term infants, birth-</td>
<td>AS</td>
<td>5</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>3.3</td>
<td>38.6</td>
<td>15.9</td>
<td>4.5</td>
<td>33.4</td>
<td>2.5</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>48 hr</td>
<td>P</td>
<td>5</td>
<td>0.2</td>
<td>0.7</td>
<td>0.6</td>
<td>4.1</td>
<td>44.8</td>
<td>9.5</td>
<td>4.4</td>
<td>32.4</td>
<td>4.1</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Months-10 months</td>
<td>AS</td>
<td>3</td>
<td>0.2</td>
<td>2.1</td>
<td>5.9</td>
<td>28.0</td>
<td>6.6</td>
<td>4.7</td>
<td>39.2</td>
<td>12.5</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>3</td>
<td>0.1</td>
<td>3.0</td>
<td>6.9</td>
<td>26.4</td>
<td>3.8</td>
<td>5.9</td>
<td>36.6</td>
<td>15.9</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2½ Years-7 Years</td>
<td>AS</td>
<td>6</td>
<td>0.1</td>
<td>0.1</td>
<td>0.4</td>
<td>3.2</td>
<td>23.2</td>
<td>4.7</td>
<td>6.1</td>
<td>51.6</td>
<td>9.3</td>
<td>0.9</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>P</td>
<td>6</td>
<td>0.1</td>
<td>0.1</td>
<td>0.4</td>
<td>3.2</td>
<td>24.8</td>
<td>3.9</td>
<td>7.4</td>
<td>49.0</td>
<td>9.8</td>
<td>0.5</td>
<td>0.1</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>19 Years-54 years</td>
<td>AS</td>
<td>4</td>
<td>0.5</td>
<td>3.4</td>
<td>24.0</td>
<td>5.2</td>
<td>6.4</td>
<td>49.7</td>
<td>8.2</td>
<td>1.3</td>
<td>0.5</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>4</td>
<td>0.4</td>
<td>3.3</td>
<td>23.4</td>
<td>5.0</td>
<td>7.1</td>
<td>49.5</td>
<td>9.2</td>
<td>1.0</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AS = abdominal subcutaneous. P = perirenal.
is likely to be between 33.5 and 45.5% of adipose tissue weight (Table 1) and, for purposes of calculation, an intermediate value of 39% may be used. Thus, if nearly all the body lipid is located in adipose tissue, approximately one-third of body weight at birth must consist of adipose tissue. Fomon (8) calculated that by age 4 months lipid is likely to account for approximately 26% of body weight of a "male reference infant." Assuming that the lipid content of adipose tissue at 6–9 months of age is approximately 63% of adipose tissue weight (a value intermediate between 68.7 and 57.7%, Table II), the lipid content of adipose tissue at age 4 months must be between 45% (the estimated average content at birth) and 63% (the estimated average content at 6–9 months of age). Thus, perhaps 50% of adipose tissue weight at age 4 months may be made up of lipid. If 26% of body weight at age 4 months consists of lipid, if nearly all body lipid is located in adipose tissue, and if lipid accounts for approximately 50% of adipose tissue weight, then approximately one-half of body weight at age 4 months must be made up of adipose tissue.

Little is known about the variability in size and composition of this body compartment among individuals of a specified age. Its magnitude as calculated from data presented here is certainly great and it seems likely that adipose tissue may play a major role in body growth, heat conservation, and energy production.

The extent of sex-related differences in size, composition, and metabolic activity at various ages remains to be elucidated. Even during infancy, the occurrence of differences would not be unexpected in view of sex-related differences demonstrated in other aspects of body composition (6). Metabolic activity of adipose tissue may be influenced by gestational age, as well as its relative size and composition. Free fatty acids from adipose tissue probably constitute an important source of energy in the early postnatal period (22–24). Low birth-weight infants may be quite handicapped by marginal or low lipid stores.

If one assumes the DNA content of the diploid cell nucleus is constant at 6.2 μg/cell (20), the cell number per gram of fresh adipose tissue may be calculated. At birth, the cell number of $19.3 \times 10^7$/g of fresh perirenal adipose tissue is significantly ($P < 0.0125$) higher than in subcutaneous adipose tissue, which has a value of $10.8 \times 10^7$. After the immediate neonatal period, the DNA content per unit weight (and thus cell number per unit weight) is lower in each succeeding group. In the older adult, the cell number is $2.9 \times 10^7$/g fresh abdominal subcutaneous adipose tissue and $4.6 \times 10^7$ in perirenal adipose tissue ($P < 0.05$). Thus, per gram of tissue, either the number of adipose cells or the number of supporting cells decreases in older individuals, or both. Histologically, adipose cells become larger (25). Perhaps this is a reflection of decreasing metabolic activity and a relatively greater depot function for these sites.

Because fat-free dry residue is a small percentage of total weight of adipose tissue, one would anticipate an inverse relationship between percentages of water and lipid. Such a relationship was, in fact, apparent in these data as had previously been reported (11) for adipose tissue of adult subjects (Fig. 2). The relationship demonstrated in Fig. 2 is also generally age related, the younger individuals having relatively less lipid and more water per gram fresh tissue.

The differences between subcutaneous and perirenal adipose tissue of individuals less than 5 years of age apparently reflects the presence of brown adipose tissue in the perirenal area. Aherne and Hull (3) demonstrated deposits of brownish-appearing adipose tissue in the perirenal, interscapular, and axillary areas of small infants. Histologically, this tissue is more cellular and has more supporting struc-
ture than adipose tissue in most other sites. Similar tissue occurs in other species, particularly those that hibernate. Brown adipose tissue is active in heat production and probably serves as a source of fatty acids for energy requirements (3). Further work is needed to define the role brown adipose tissue may play in the energy supply of the neonate.

The fatty acid components show a variation with age that is probably related to the available substrate. Longenecker (26) has shown that when the substrate for adipose formation is primarily carbohydrate, large amounts of palmitic and palmitoleic acids result. While the primary fetal substrate is probably glucose (27), this changes at birth so that fat and protein are also major sources of substrate. Dietary sources of fat available after birth are reflected by the presence of a large proportion of oleic and linoleic acid in older individuals. Similar findings in the infant buccal fat pad have been reported (28). The increased carbohydrate available to the infant of a diabetic mother thus predictably produces a greater adipose tissue compartment (29). The fatty acid composition of such tissue would be expected to be higher in palmitic and palmitoleic acids as well.

The higher level of linoleic acid in perirenal adipose tissue of stillborn infants, which persists in the neonates, possibly reflects another way in which brown adipose tissue differs from white. Since histologic confirmation is not available, this remains speculative.

The proportions of fatty acids in the adult samples do not differ from the larger series reviewed by Insull and Bartsch (16).

SUMMARY

Analysis of adipose tissue specimens obtained at necropsy from individuals ranging from birth to 86 years of age was carried out for water, lipid, nitrogen, DNA, and fatty acids. Both subcutaneous and perirenal samples were studied in each instance. The water, lipid, nitrogen, and DNA content as well as the fatty acid proportions are age related.

The lipid content of adipose tissue accounted for only about 40% of adipose tissue weight in the newborn period and increased with increasing age to 75% in the adult. Concentrations of water, nitrogen, and DNA declined with age.

Technical assistance of Mrs. J. Eash and Mr. D. W. Andersen is gratefully acknowledged.

REFERENCES


